What is claimed is:

1. A method of calculating a desired axis motion of a wheeled base from an overall desired motion of the wheeled base, the wheeled base having at least two wheels, each wheel having two axis which define two degrees of freedom for that wheel, each wheel having an attachment point on the base, the method comprising the steps of:

receiving an inputted motion vector for an overall desired motion of the wheeled base;

calculating from the inputted vector a desired two dimensional motion vector for each of the attachment points;

mapping the motion vector of one of the attachment points to an axis motion for each of the two axes associated with the one attachment point, so that driving the two axes of the associated wheel will result in the desired base motion of the one attachment point; and

repeating the previous step for each of the attachment points.

2. A method of calculating a desired axis motion as recited in claim 1, wherein the step of calculating the two dimensional motion vector for each of the attachment points is characterized by the equations:

$$\dot{x}_{dWi} = \dot{x}_d - y_{wi}\dot{\psi}_d$$

$$\dot{y}_{dWi} = \dot{y}_d + x_{wi}\dot{\psi}_d$$

wherein

$\dot{x}_{dWi}$ is the desired wheel attachment point velocity in the x-direction of the base coordinates for each wheel i in meters per second,

$\dot{x}_d$ is the desired base velocity in the x-direction of the base coordinates in meters per second,

$\dot{\psi}_d$ is the desired rotational velocity in base coordinates in radians per second,

$\dot{y}_{dWi}$ is the desired wheel attachment point velocity in the y direction of the base coordinates for each wheel i in meters per second,

$\dot{y}_d$ is the desired base velocity in the x-direction of the base coordinates in meters per second,

x_{Wi} is the x-component of the wheel attachment point of wheel i in base coordinates in meters, and

y_{Wi} is the y-component of the wheel attachment point of wheel i in base coordinates in meters.

3. A method of calculating a desired axis motion as recited in claim 1, wherein all of the wheels of the base have a caster that is equal to zero and the steps of mapping the motion vectors of the attachment points to axis motions is characterized by the equations:

$$\theta_{dWi} = \arctan2(\dot{y}_{dWi}, \dot{x}_{dWi})$$

$$\dot{\mu}_{dWi} = \sqrt{\dot{x}_{dWi}^2 + \dot{y}_{dWi}^2}$$

$$s_{dWi} = \sigma_{Wi}\theta_{dWi}$$

$$\dot{t}_{dWi} = \frac{\tau_{Wi}}{r_{Wi}}\dot{\mu}_{dWi}$$

wherein

θ_{dWi} is the desired steering angle for 2-DOFW i, in radians,

$\dot{y}_{dWi}$ is the desired wheel attachment point velocity in the y direction of the base coordinates for each wheel i in meters per second,

$\dot{x}_{dWi}$ is the desired wheel attachment point velocity in the x-direction of the base coordinates for each wheel i in meters per second,

$\dot{\mu}_{dWi}$ is the desired velocity magnitude for wheel i in meters per second,

s_{dWi} is the desired steering angle with respect to base coordinates of wheel i in encoders,

σ_{Wi} is the steering axis "encoder pitch" for the steering axis of 2-DOFW i expressed in encoders per radian,

$\dot{t}_{dWi}$ is the desired velocity of the translation axis for wheel i in encoders per second,

τ_{Wi} is the translation axis "encoder pitch" for wheel i in encoders per radian, and

r_{Wi} is the wheel radius of wheel i in meters per radian.

4. A method of calculating a desired axis motion as recited in claim 1, wherein all of the wheels of the base have a caster that is not equal to zero and the steps of mapping the motion vectors of the attachment points to axis motions is characterized by the equations:

$$\theta_{mWi} = \frac{s_{mWi}}{\sigma_{Wi}};$$

$$\dot{s}_{dWi} = \frac{\sigma_{Wi}}{c_{Wi}}\left(\dot{y}_{dWi}\cos(\theta_{mWi}) - \dot{x}_{dWi}\sin(\theta_{mWi})\right) - \dot{\psi}_d; \text{ and}$$

$$\dot{t}_{dWi} = \frac{\tau_{Wi}}{r_{Wi}}\left(\dot{x}_{dWi}\cos(\theta_{mWi}) + \dot{y}_{dWi}\sin(\theta_{mWi})\right),$$

wherein

θ_{mWi} is the measured angle of the steering axis of wheel i with respect to base coordinates in radians,

s_{mWi} is the measured angle of wheel i with respect to base coordinates in encoders,

σ_{Wi} is the steering axis "encoder pitch" for the steering axis of 2-DOFW-i expressed in encoders per radian,

$\dot{s}_{dWi}$ is the desired steering axis velocity of wheel i in encoders per second,

c_{Wi} is the amount of caster offset in meters per radian,

$\dot{y}_{dWi}$ is the desired wheel attachment point velocity in the y direction of the base coordinate for each wheel i in meters per second,

$\dot{x}_{dWi}$ is the desired wheel attachment point velocity in the x-direction of the base coordinates for each wheel, i in meters per second,

$\dot{\psi}_d$ is the desired base rotation velocity in radians per second,

$\dot{t}_{dWi}$ is the desired velocity of the translation axis for wheel i in encoders per second,

τ_{Wi} is the encoder pitch for 2DOFW i expressed in encoders per radians, and

r_{Wi} is the radius of the 2DOFW i in meters per radian.

5. A method of providing a control envelope for axes on a wheeled base, the wheeled base having at least two wheels, each wheel having two axes which

define two degrees of freedom for that wheel, the control envelope ensuring that none of the wheel axes are commanded to move in a manner that they are not capable, the method comprising the steps of:

defining for each of the axes of each of the wheels a maximum possible range of motion that will be permitted during an allotted control period;

receiving an inputted motion vector for an overall desired motion of the wheeled base;

calculating from the inputted vector a desired axis motion for each of the axes of each of the wheels, so that driving all of the axes will result in the overall desired motion of the base;

determining if any of the desired axis motions are not within the permitted range of motion previously defined for that axis; and

modifying as little as possible the overall desired motion of the base if required by the previous step such that all of the corresponding desired axis motions are within the permitted ranges of axis motion.

6. A method of estimating rotation of a wheeled base relative to a surface during a discrete time interval Δt, the base having at least two wheels each pivotably and rotatably mounted thereon for contacting the surface and driving the base and surface relative to one another, the method comprising the steps of:

calculating an apparent motion for each of the wheels during the time interval Δt;

calculating a rotation of the base for each possible pair of the wheels based on the apparent motion calculated for each of the wheels; and

averaging the results of the previous step.

7. A method of estimating rotation of a wheeled base as recited in claim 6, wherein the step of calculating an apparent motion of each wheel is represented by the equations:

$$x'_{Wi} = x_{Wi} + \Delta t_{mWi}\cos(\theta_{mWi}) - \Delta s_{mWi}\sin(\theta_{mWi})\text{; and}$$

$$y'_{Wi} = y_{Wi} + \Delta s_{mWi}\cos(\theta_{mWi}) + \Delta t_{mWi}\sin(\theta_{mWi}),$$

wherein

x'_{Wi} is the x-component of the attachment point of wheel i after base motion during one control cycle in meters,

x_{Wi} is the x-component of the wheel attachment point of wheel i in base coordinates in meters,

Δt_{mWi} is the measured motion of the translation axis of wheel i during one control cycle expressed in meters,

θ_{mWi} is the measured angle of the steering axis of wheel i with respect to base coordinates in radians,

Δs_{mWi} is the measured motion of the steering axis of wheel i during one control cycle expressed in meters,

y'_{Wi} is the y-component of the attachment point of wheel i after base motion during one control cycle in meters, and

y_{Wi} is the y-component of the wheel attachment point of wheel i in base coordinates in meters.

8. A method of estimating rotation of a wheeled base as recited in claim 7, wherein each wheel has a steering axis and a rolling or translation axis, the two axis for each of the wheels being offset from one another such that the caster does not equal zero.

9. A method of estimating rotation of a wheeled base as recited in claim 7, wherein each wheel has a steering axis and a rolling or translation axis, the two axis for each of the wheels intersecting such that the caster equals zero.

10. A method of estimating rotation of a wheeled base as recited in claim 6, wherein the steps of calculating a rotation of the base for each possible pair of the wheels and averaging the results are represented by the equation:

$$\Delta\psi_e = \tfrac{1}{M}\sum_{\forall\{j,k\}} \operatorname{arctan2}(y'_{Wk} - y'_{Wj}, x'_{Wk} - x'_{Wj}) - \operatorname{arctan2}(y_{Wk} - y_{Wj}, x_{Wk} - x_{Wj}),$$

wherein

$\Delta\psi_e$ is the calculated rotation change in radians,

m is the number of unique pair combinations of N wheels,

j and k are index variables of a possible wheel pair combination,

y'_{Wk} is the y-component of the attachment point of wheel k after base motion during one control cycle in meters,

y'_{Wj} is the y-component of the attachment point of wheel j after base motion during one control cycle in meters,

x'_{Wk} is the x-component of the attachment point of wheel k after base motion during one control cycle in meters,

x'_{Wj} is the x-component of the attachment point of wheel j after base motion during one control cycle in meters,

y_{Wk} is the y-component of the wheel attachment point of wheel k in base coordinates in meters,

y_{Wj} is the y-component of the wheel attachment point of wheel j in base coordinates in meters,

x_{Wk} is the x-component of the wheel attachment point of wheel k in base coordinates in meters, and

x_{Wj} is the x-component of the wheel attachment point of wheel j in base coordinates in meters.

11. A method of calculating position and orientation of a wheeled base relative to a world coordinate system fixed to a surface, the base having a base coordinate system fixed thereto and at least two wheels each pivotably and rotatably mounted to the base at an attachment point for contacting the surface and driving the base and surface relative to one another, the method comprising the steps of:

calculating a steering angle for each of the wheels;

calculating a measured translation distance for each of the wheels traveled over a time Δt elapsed during a control cycle;

calculating an apparent motion for each of the wheels based on the steering angle and measured translation calculated;

calculating an apparent position in base coordinates for each of the wheels by adding the calculated motion to the wheel attachment point at the beginning of the control cycle;

calculating a rotation of the base for each possible pair of the wheels based on the apparent motion calculated for each of the wheels;

calculating a total change in base rotation by averaging the results of the previous step;

calculating a total change in translation coordinates by averaging the apparent motion of each of the wheels, taking into account the base rotation calculated in the previous step since the beginning of the control cycle;

calculating a summed-up position and orientation of the mobile base in the fixed world coordinates by adding the total change in base angle to an existing angle estimate and adding the total change in translation coordinates to an existing estimate of translation coordinates.

12. A method of calculating position and orientation of a wheeled base as recited in claim 11, wherein the step of calculating the total change in base rotation is characterized by the equation:

$$\Delta\psi_e = \tfrac{1}{M} \sum_{\forall\{j,k\}} \operatorname{arctan2}(y'_{Wk} - y'_{Wj}, x'_{Wk} - x'_{Wj}) - \operatorname{arctan2}(y_{Wk} - y_{Wj}, x_{Wk} - x_{Wj}),$$

wherein

$\Delta\psi_e$ is the calculated rotation change in radians,

m is the number of unique pair combinations of N wheels,

j and k are index variables of a possible wheel pair combination,

y'_{Wk} is the y-component of the attachment point of wheel k after base motion during one control cycle in meters,

y'_{Wj} is the y-component of the attachment point of wheel j after base motion during one control cycle in meters,

x'_{Wk} is the x-component of the attachment point of wheel k after base motion during one control cycle in meters,

x'_{Wj} is the x-component of the attachment point of wheel j after base motion during one control cycle in meters,

y_{Wk} is the y-component of the wheel attachment point of wheel k in base coordinates in meters,

y_{Wj} is the y-component of the wheel attachment point of wheel j in base coordinates in meters,

x_{Wk} is the x-component of the wheel attachment point of wheel k in base coordinated in meters, and

x_{Wj} is the x-component of the wheel attachment point of wheel j in base coordinated in meters.

13. A method of calculating position and orientation of a wheeled base as recited in claim 11, wherein the step of calculating the total change in translation coordinates is characterized by the equations:

$$\Delta x_e = \tfrac{1}{N}\sum_{i=1}^{N}\left(x'_{Wi} + y_{Wi}\Delta\psi_e\right)$$

$$\Delta y_e = \tfrac{1}{N}\sum_{i=1}^{N}\left(y'_{Wi} - x_{Wi}\Delta\psi_e\right)$$

wherein

Δx_e is the estimated change of the base location in the x-direction in base coordinates since the previous control cycle in meters,

N is the number of wheels,

i is an index variable,

x'_{Wi} is the x-component of the attachment point of wheel i after base motion during one control cycle in meters,

x_{Wi} is the x-component of the wheel attachment point of wheel i in base coordinates in meters,

y_{Wi} is the y-component of the wheel attachment point of wheel i in base coordinate in meters,

$\Delta\psi_e$ is the estimated rotational change of the base location in base coordinates since the previous control cycle in meters,

Δy_e is the estimated change of the base location in the y-direction in base coordinates since the previous control cycle in meters, and

y'_{Wi} is the y-component of the attachment point of wheel i after base motion during one control cycle in meters.

14. A method of calculating position and orientation of a wheeled base as recited in claim 11, wherein the step of calculating a summed-up position and orientation of the mobile base is characterized by the equations:

$$\psi_{eB} = \psi_{eB} + \Delta\psi_e,$$

$$x_{eB} = x_{eB} + \Delta x_e \cos(\psi_{eB}) - \Delta y_e \sin(\psi_{eB}), \text{ and}$$

$$y_{eB} = y_{eB} + \Delta y_e \cos(\psi_{eB}) + \Delta x_e \sin(\psi_{eB})$$

wherein

ψ_{eB} is the estimated rotational position of the base coordinate frame origin with respect to a fixed world coordinate frame,

$\Delta\psi_e$ is the estimated rotational change of the base location in base coordinates since the previous control cycle in meters,

x_{eB} is the estimated position of the base coordinate frame origin in the x-direction of a fixed world coordinate frame,

Δx_e is the estimated change of the base location in the x-direction in base coordinates since the previous control cycle in meters,

Δy_e is the estimated change of the base location in the y-direction in base coordinates since the previous control cycle in meters, and

y_{eB} is the estimated position of the base coordinate frame origin in the y-direction of a fixed world coordinate frame.

15. A method for controlling the motion of a wheeled base with respect to a surface, the base having a base coordinate system fixed thereto and at least two wheels each pivotably and rotatably mounted to the base at an attachment point for

contacting the surface and driving the base and surface relative to one another, each wheel having a plurality of axes, the method comprising the steps of:

reading an input vector from a host processor;

mapping the input vector to a desired axis motion vector for each of the axes;

sending the desired axis motion vector to an axis controller for each of the axes;

estimating a motion of the base traveled during a discrete time interval Δt;

calculating a position and an orientation of the base in a set of world coordinates.

16. A method for controlling the motion of a wheeled base as recited in claim 15, wherein the steps of estimating a motion of the base and calculating a position and orientation of the base further comprise the steps of:

calculating a steering angle for each of the wheels;

calculating a measured translation distance for each of the wheels traveled over a time Δt elapsed during a control cycle;

calculating an apparent motion for each of the wheels based on the steering angle and measured translation calculated;

calculating an apparent position in base coordinates for each of the wheels by adding the calculated motion to the wheel attachment point at the beginning of the control cycle

calculating a rotation of the base for each possible pair of the wheels based on the apparent motion calculated for each of the wheels;

calculating a total change in base rotation by averaging the results of the previous step;

calculating a total change in translation coordinates by averaging the apparent motion of each of the wheels, taking into account the base rotation calculated in the previous step since the beginning of the control cycle;

calculating a summed-up position and orientation of the mobile base in the fixed world coordinates by adding the total change in base angle to an

existing angle estimate and adding a rotated total change in translation coordinates to an existing estimate of translation coordinates.

17. A method for controlling the motion of a wheeled base as recited in claim 16, wherein the step of calculating the total change in base rotation is characterized by the equation:

$$\Delta\psi_e = \tfrac{1}{M}\sum_{\forall\{j,k\}} \operatorname{arctan2}(y'_{Wk} - y'_{Wj}, x'_{Wk} - x'_{Wj}) - \operatorname{arctan2}(y_{Wk} - y_{Wj}, x_{Wk} - x_{Wj}),$$

wherein

$\Delta\psi_e$ is the calculated rotation change in radians,

m is the number of unique pair combinations of N wheels,

j and k are index variables of a possible wheel pair combination,

y'_{Wk} is the y-component of the attachment point of wheel k after base motion during one control cycle in meters,

y'_{Wj} is the y-component of the attachment point of wheel j after base motion during one control cycle in meters,

x'_{Wk} is the x-component of the attachment point of wheel k after base motion during one control cycle in meters,

x'_{Wj} is the x-component of the attachment point of wheel j after base motion during one control cycle in meters,

y_{Wk} is the y-component of the wheel attachment point of wheel k in base coordinates in meters,

y_{Wj} is the y-component of the wheel attachment point of wheel j in base coordinates in meters,

x_{Wk} is the x-component of the wheel attachment point of wheel k in base coordinates in meters, and

x_{Wj} is the x-component of the wheel attachment point of wheel j in base coordinates in meters.

18. A method for controlling the motion of a wheeled base as recited in claim 16, wherein the step of calculating the total change in translation coordinates is characterized by the equations:

$$\Delta x_e = \tfrac{1}{N}\sum_{i=1}^{N}\left(x'_{Wi} + y_{Wi}\Delta\psi_e\right); \text{ and}$$

$$\Delta y_e = \tfrac{1}{N}\sum_{i=1}^{N}\left(y'_{Wi} - x_{Wi}\Delta\psi_e\right),$$

wherein

Δx_e is the estimated change of the base location in the x-direction in base coordinates since the previous control cycle in meters,

N is the number of wheels,

i is an index variable,

x'_{Wi} is the x-component of the attachment point of wheel *i* after base motion during one control cycle in meters,

x_{Wi} is the x-component of the wheel attachment point of wheel *i* in base coordinates in meters,

y_{Wi} is the y-component of the wheel attachment point of wheel *i* in base coordinate in meters,

$\Delta\psi_e$ is the estimated rotational change of the base location in base coordinates since the previous control cycle in meters,

Δy_e is the estimated change of the base location in the y-direction in base coordinates since the previous control cycle in meters, and

y'_{Wi} is the y-component of the attachment point of wheel *i* after base motion during one control cycle in meters.

19. A method for controlling the motion of a wheeled base as recited in claim 16, wherein the step of calculating a summed-up position and orientation of the mobile base is characterized by the equations:

$$\psi_{eB} = \psi_{eB} + \Delta\psi_e,$$

$$x_{eB} = x_{eB} + \Delta x_e \cos(\psi_{eB}) - \Delta y_e \sin(\psi_{eB}), \text{ and}$$

$y_{eB} = y_{eB} + \Delta y_e \cos(\psi_{eB}) + \Delta x_e \sin(\psi_{eB})$

wherein

ψ_{eB} is the estimated rotational position of the base coordinate frame origin with respect to a fixed world coordinate frame,

$\Delta\psi_e$ is the estimated rotational change of the base location in base coordinates since the previous control cycle in meters,

x_{eB} is the estimated position of the base coordinate frame origin in the x-direction of a fixed world coordinate frame,

Δx_e is the estimated change of the base location in the x-direction in base coordinates since the previous control cycle in meters,

Δy_e is the estimated change of the base location in the y-direction in base coordinates since the previous control cycle in meters, and

y_{eB} is the estimated position of the base coordinate frame origin in the y-direction of a fixed world coordinate frame.

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20. A method for controlling the motion of a wheeled base with respect to a surface, the base having a base coordinate system fixed thereto and at least two wheels each pivotably and rotatably mounted to the base for contacting the surface and driving the base and surface relative to one another, each wheel having a plurality of axes, the method comprising the steps of:

reading an input vector from a host processor;

mapping the input vector to a desired axis motion vector for each of the axes;

calculating a control envelope for each of the axes;

determining whether the desired axis motion vector lies within the control envelope for each of the axes;

calculating a modified axis motion vector for each of the axes in which the desired axis motion vector does not lie within the control envelope;

sending the desired axis motion vector or modified axis motion vector to an axis controller for each of the axes;

estimating a motion of the base traveled during a discrete time interval Δt;

calculating a position and an orientation of the base in a set of world coordinates; and

repeating the previous steps continuously until commanded to stop.

21. A mobile base movable relative to a surface, the base comprising: at least two wheels pivotably and rotatably mounted to the base, each wheel having a steering axis and a rotation axis;

drive means for rotating the wheels along the surface;

steering means for pivoting the wheels with respect to the surface; and

controller means for controlling the motion of the base, wherein the controller means includes means for reading an input vector from a host processor, mapping the input vector to a desired axis motion vector for each of the axes, calculating a control envelope for each of the axes, determining whether the axis motion vector lies within the control envelope for each of the axes, calculating a modified axis motion vector when the axis motion vector does not lie within the control envelope, sending the axis motion vector or modified axis motion vector to an axis controller for each of the axes, estimating a motion of the base traveled during a discrete time interval Δt, calculating a position and an orientation of the base in a set of world coordinates, and repeating the previous steps continuously until commanded to stop.

22. A mobile base movable relative to a surface, the base comprising:

at least three wheels pivotably and rotatably mounted to the base, each wheel having a steering axis and a rotation axis;

drive means for rotating the wheels along the surface;

first encoder means for sensing the rotation of each of the wheels and outputting a signal for each wheel in response thereto;

steering means for pivoting the wheels with respect to the surface;

second encoder means for sensing the pivoting of each of the wheels and outputting a signal for each wheel in response thereto; and

a processor for estimating a rotation of the base relative to the surface during a discrete time interval Δt by receiving the output signals from the first and second encoder means, calculating from the signals an apparent motion for each of the wheels during the time interval Δt, calculating from the apparent motions a rotation of the base during the time interval Δt for each possible pair of wheels, and averaging the results of the calculated rotations.

23. A mobile base movable relative to a surface, the base comprising:

at least two wheels pivotably and rotatably mounted to the base, each wheel having a steering axis and a rotation axis;

drive means for rotating the wheels along the surface;

steering means for pivoting the wheels with respect to the surface;

a controller for supplying power to the drive means and the steering means; and

a processor for sending command signals to the controller and for calculating a control envelope to ensure that commands are not sent to the controller that cannot be executed by the drive means or the steering means, the processor calculating the control envelope by receiving an input motion signal indicating an overall desired motion of the base, calculating from the input signal a desired axis motion for each of the wheel axes that will achieve the overall desired motion of the base, determining if each of the desired axis motions is within an associated range of motion predefined for each of the axes, and, if required, modifying as little as possible the overall desired motion of the base until all of the corresponding desired axis motions are within the associated predefined ranges of axis motion.

24. A method of providing a control envelope for axes on a wheeled base, the wheeled base having at least two wheels, each wheel having two axes which

define two degrees of freedom for that wheel, the control envelope ensuring that none of the wheel axes are commanded to move in a manner that they are not capable, the method comprising the steps of:

defining for each of the axes of each of the wheels a maximum permitted range of torque;

receiving an inputted force vector for an overall desired resultant force of the wheeled base;

calculating from the inputted vector a desired axis torque for each of the axes of each of the wheels, so that driving all of the axes will result in the overall desired force of the base;

determining if any of the desired axis torques are not within the permitted range of torque previously defined for that axis; and

modifying as little as possible the overall desired force input vector of the base if required by the previous step such that all of the corresponding desired axis torques are within the permitted ranges of axis torques.

25. A method of calculating position and orientation of a wheeled base as recited in claim 11, wherein the steps of calculating the total change in rotation and translation coordinates are characterized by the equation:

$$\vec{m}_e = \tfrac{1}{\Delta t} C_x^{\#} \left[\Delta s_{mW1}, \Delta t_{mW1}, \ldots, \Delta s_{mWi}, \Delta t_{mWi}, \ldots, \Delta s_{mWN}, \Delta t_{mWN} \right]^T$$

wherein

$\vec{m}_e$ is the estimated mobile base motion in base coordinates.

Δt is the time elapsed during a control cycle (s),

$C_x^{\#}$ is the velocity estimation matrix, a generalized left inverse of the constraint matrix,

Δs_{mWi} is the measured motion of the steering axis of wheel i during one control cycle,

Δt_{mWi} is the measured motion of the translation axis of wheel i during one control cycle, and

N is the number of wheels mounted to the base.

26. A mobile base movable relative to a surface, the base comprising:

a main housing;

at least two wheels pivotably and rotatably mounted to the housing , each wheel having a steering axis and a rotation axis with the steering and rotation axes nonintersecting and offset by a known caster distance;

drive means for rotating the wheels to roll along the surface;

steering means for pivoting the wheels and changing their heading with respect to the surface; and

controller means for

reading an input vector from a host processor, wherein the input vector is a three dimensional force torque vector,

reading the steering axis headings,

calculating a desired torque for each steering and rotation axis such that at any given time, the calculated resultant forces on the base reflect the input vector, regardless of the positions of the steering and rotation axes, and

commanding the calculated torque to each steering and rotation axis.

Sub B3

27. An apparatus as described in claim 26 wherein the controller means includes a dynamic model such that the controller means compensates for undesired motion of the base due to various motions of the wheels.

28. An apparatus as described in claim 26 wherein the calculated torque of each steering and rotation axis is computed from the input vector and a generalized inverse of a constraint matrix, C, the constraint matrix being defined by the following kinematic relationship:

$$\vec{m}_a = C\vec{m}_x$$

where $\vec{m}_a$ represents a motion axis vector and $\vec{m}_x$ represents actual mobile base motion.

29. An apparatus as described in claim 28 wherein the generalized inverse of C is chosen such that a sum of squares of the axis torques is minimized.

30. An apparatus as described in claim 28 wherein the generalized inverse of C is chosen such that a sum of squares of wheel contact forces is minimized.

Sub B3

31. An apparatus as described in claim 28 wherein there is an instantaneous power for each of the steering and rotation axes and wherein the generalized inverse of C is chosen such that a sum of the instantaneous powers of all of the axes is minimized.